

JOURNAL OF THE
BOSTON SOCIETY
OF
CIVIL ENGINEERS

MAY, 1928

Featuring

**Water-Cement Ratio Applied
to Concrete Highway Pavements — With Discussion**

**Traffic Regulations for General
Use**

Resurfacing Pavements



Vol. XV

No. 5

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Published Monthly, except July and August, by the Society
715 Tremont Temple, Boston, Massachusetts

Subscription Price, \$4.00 a Year (10 Copies)
50 Cents a Copy

Copyright, 1928, by the Boston Society of Civil Engineers.
Entered as second-class matter, January 15, 1914, at the Post Office
at Boston, Mass., under Act of August 24, 1912.

Acceptance for mailing at special rate of postage provided for in
Section 1103, Act of October 3, 1917, authorized on July 16, 1918.

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BOSTON
WRIGHT & POTTER PRINTING COMPANY
32 DERNE STREET

JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS

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THE PRACTICAL APPLICATION OF THE WATER-CEMENT RATIO METHOD OF PROPORTIONING AND CONTROLLING CONCRETE AS APPLIED TO HIGHWAY PAVEMENTS

BY WALLACE F. PURRINGTON*

(Presented before the Highway Section, B. S. C. E., February 21, 1928)

UNTIL two years ago the New Hampshire Highway Department determined the quality of its concrete based on an arbitrary mix. Engineers considered this as unscientific and not producing the results that should be obtained. By this method advantage could not be taken of the difference in quality and grading of various aggregates. Because of this our Department was purchasing concrete at higher prices than was warranted.

The first natural question that would arise when building a structure or pavement would be, how strong must this be designed to withstand the stresses that will have to be applied to it?

Assuming that this point is determined, the next logical thought that would interest the purchaser would be the question of cost. It is assumed that State highway departments, like every one else, have a limited amount of money to do business with, and, like the individual, are anxious to make a dollar go as far as possible.

Bridge structures are put up economically by using well-founded principles of design. These principles are not founded upon chance, but are the results of mathematical relations that have been slowly worked out. It has been the practice to divide concrete structures into three

* Materials Engineer of the New Hampshire Highway Department.

general classifications, such as mass, reinforced and highways. The usual practice for mass work has been to specify a 1:3:6 or a 1:2½:5 mix; for reinforced concrete, a 1:2:4 mix; and for pavement, a mix as rich as 1:2:3. To strictly comply with the specifications neither the contractor nor the inspector had any latitude to vary the mix that maximum results might be obtained from a definite set of conditions. There is not an engineer within my hearing who has not at some time wished that the mix he was using could be changed so that more workable concrete might be obtained.

Engineers are now becoming interested in the design of concrete mixes as well as in the design of the structure itself.

The purpose of this paper is to outline the practical application of the method of concrete design as applied to several highway pavement jobs, pointing out the various steps to carry this out and giving the results obtained.

This problem like many others is based on a premise. Our premise will be that the one most important condition pertaining to the production of concrete is the relation of water to cement. There are other factors entering into the manufacture of concrete which have a secondary bearing on our premise. These will be taken up in their proper order. The popular designation of our premise is the water-cement ratio law. This has been stated by the Portland Cement Association as follows:

For given materials and conditions of manipulation, the strength of concrete is determined solely by the ratio of the volume of mixing water to the volume of cement as long as the mixture is plastic and workable.

The information to be covered in this paper will be based on observations made upon four highway pavement jobs which totaled 9.70 miles and contained 102,476 square yards of concrete. Two of these jobs were built by the same contractor using similar equipment, while quite different apparatus, in part, was used by the other contractor. The subject matter will include the following topics:

1. Preliminary inspection of materials.
2. Testing of materials.
3. Design of mix by the calculation method.
4. Selling the idea to the contractor.
5. Starting and controlling the job.
6. Inspection.
7. Results obtained.
8. Opinions of interested parties.

PRELIMINARY INSPECTION OF MATERIALS

The preliminary inspection of materials is very important, and the subsequent results are determined by the amount of work done at this time. Samples of the coarse and fine aggregates from the sources that are logical for the job are taken by some person from the laboratory. These should be carefully taken and should be representative of the quality and grading that could be supplied to the job. While it will be shown later that nearly any clean aggregates may be used in concrete, in our preliminary work we should use as great care as possible to choose the most economical material available. In general, the most economical aggregates are those which, when designed for a definite strength, use the least cement and the smallest quantity of coarse aggregate to the cubic yard. At this point it would be well to explain that the term "strength" will be used quite often. The other desirable qualities of concrete are not lost sight of, however. It is just as important to have dense concrete as to have the material highly resistant to abrasion. Fortunately, the other desirable qualities are functions of strength when economy is considered. Using the proper amounts of aggregates in both cases, we would not expect concrete designed for 3,000 pounds per square inch to have the same degree of density or the same abrasion loss, as that concrete designed for 1,500 pounds per square inch.

When local materials are under consideration for use, the accurate determination of the proportions that are to be used before the crusher and screening plant is in operation is a little difficult. Experience has shown that it is not impossible to determine these proportions approximately when the sizes of the revolving screens are known. There are many contractors that still believe that they can set up a small plant and produce aggregates under all sorts of weather conditions and compete with the modern sand and gravel producer. The author has seen several of these small plants operating, and wonders if the owner ever saw "a new dollar for the old."

TESTING OF MATERIALS

The whole scheme that we are discussing presupposes that the materials are clean, structurally sound and of standard quality. To this end, we test the cement, fine and coarse aggregate and in some cases the water. At present we are relying upon the modified Deval abrasion test to give us an idea of the acceptability of the stone or gravel.

Some one at some time conceived the idea that the measurement of the quality of sand for concrete could be carried out by the comparison of its strength tested in a certain way with a standard sand tested under the same conditions. We believe that this manner of testing is absolutely wrong and without foundation in theory or test. Just so long as the sand under test is coarser than the standard sand we should expect to get as high or higher results. This test penalizes a fine sand. Every engineer knows that there would be no objections to the use of a fine sand if it were used under the proper conditions. Probably there is no one subject that makes the engineer or user more skeptical of laboratory results than reports that he has occasionally received relating to the quality of sands.

When you submit samples of sand to the laboratory for test you are anxious to know whether they are clean, structurally sound, and you should be also interested in their economy. You are not particularly interested in whether this sand meets the requirements of some arbitrarily standard sand. What you want to know is, will this sand make good concrete? In other words, will this sand either under test or on the job, be strong enough to use. It is quite as possible to design the strength of a sand mortar as it is to design the strength of concrete.

For nearly a year we have been making up mortar specimens of sand, using a water-cement ratio of 0.90. We start with a certain amount of cement to which is added the amount of water which will give this water-cement ratio. When this is thoroughly mixed, enough sand is added to give a flow of 200, using a flow-table designed by the Bureau of Public Roads. Two-inch cube molds are then filled and after storage in a damp atmosphere for twenty-four hours are stored in water for six days and twenty-seven days longer. At the end of this time these are broken. In order to be classed as a normal sand the cubes should not break at less than 1,800 pounds per square inch in seven days, nor less than 3,000 pounds per square inch in twenty-eight days. Sands showing a strength less than these figures would be classed as weak.

On the basis of the sand being normal, we would advise the engineer that this sand would be satisfactory for use in concrete, allowing the use of $5\frac{1}{2}$ gallons of water to the bag of cement. If the sand showed low strength we would advise that not over 5 gallons be used. By cutting down the allowance of water we would thereby cut down the yield. Under ordinary conditions this fact would discourage its use.

We take the position that under the proper conditions *any clean* — and we would emphasize the word *clean* — and structurally sound sand may be used in the manufacture of concrete.

Your reply to this would be, in effect, that a weak or an extremely fine sand would not be economical. When you reply in this manner you are "beside the point." The primary function of a testing laboratory is to determine the *quality* of materials, not to study economics. When the quality of the material under observation has been determined, the laboratory might properly *advise* interested persons as to its economical use. We will show later that this advice has been to the mutual advantage of both the contractors and the State.

DESIGN OF THE MIX BY THE CALCULATION METHOD

The next step in our problem, after the choice of materials has been made, is to take these materials and combine them with cement in the most economical way. There are two schemes by which this can be done. These are termed the trial and calculation methods. There is no great advantage to the State in letting the contractor use the trial method on a job that calls for a large quantity of concrete. Carrying out this method a contractor is told the amount of water that can be used to a bag of cement, and then he manipulates his aggregates by trial in such a way that he gets the most workable mix. This does not necessarily give the most economical combinations of material. If the water-cement ratio scheme was dependent upon this, in all probability neither the contractor nor the State would be satisfied with the results obtained.

We determine all of our mix proportions by the calculation method. This method and all the steps involved are clearly explained in the 1927 edition, "Design and Control of Concrete Mixes," published by the Portland Cement Association. The mathematics involved is very simple. A set of scales, screens and containers for determining the weight per cubic foot is all the equipment necessary.

Let us now take up the steps that are necessary to design a mix of concrete for use in a highway pavement job in New Hampshire. We state in our specifications that the contractor shall not use more than $5\frac{1}{2}$ gallons of water (including the water in the aggregate) to each bag of cement (assuming the cement to weigh 94 pounds). This is a fixed value and cannot be changed. On a pavement job at the best the proportioning will never be carried on as accurately as in the laboratory, so we refer to the well-known Abram's Curve, and find that $5\frac{1}{2}$ gallons of water hits the B Curve at about 2,700 pounds. This, then, becomes our basis of design. We do not want too sloppy a mix, neither do we want it to be too dry; therefore we decide that a mix which will give a

slump of from 3 to 4 inches will produce the right workability. We have now determined the consistency of that we are aiming for.

When we mix cement and water together we form a mineral glue. We now want to use this glue to coat the sand and stone particles and cement them together. If we used all sand particles we would find that our glue would not go very far. If we used all stone particles we would find that our glue would go far enough, but that we would have too high a percentage of voids, and we would lose the desirable quality of density. By the use of more sand and less stone we finally come to a place where we get the mix which will give the densest, most economical and strongest concrete for the given conditions. It is not the purpose in this paper to give all the details of the method of calculation, only repeating the statement that this is easily available to interested parties.

We report to the contractor the mix proportions on the dry and rodded as well as on the field basis. On the dry and rodded basis is determined the barrels of cement and the quantities of aggregates necessary for a cubic yard of concrete. When the actual operation of mixing commences, the contractor is interested in the quantity of materials he will have to use under the conditions prevailing at the time. As all our contractors proportion by volume, it is necessary to determine the percentage of moisture and the weight of the material per cubic foot in the damp and loose condition. The bulking factor is taken account of in our design.

At this point we have worked up the preliminary data, and are now ready to furnish the information to the contractor.

SELLING THE IDEA TO THE CONTRACTOR

Our Department takes the position that a close co-operation between its engineers and the contractor will eventually be reflected in lower prices for projects. To this end, for this type of work, it places at the disposal of any contractor the facilities of its laboratory, both preceding and during the progress of the job. This fact is definitely written into the specifications.

The contractor's first reaction to this offer may be skepticism. There may be two definite reasons, based possibly on past experiences, for his unfavorable attitude. He might be suspicious that some one was trying to "put something over on him," or that the laboratory was too theoretical.

We are perfectly safe in saying that our State Highway Commissioner would never have approved or adopted the water-cement ratio

method unless he felt that quality concrete could be produced at lower cost. Neither would he have tolerated the carrying on of experiments which would have resulted in increased costs or hindrance to the contractor.

Assuming, then, that the interests of the contractor and the State are identical, in that they both want a good job done, and that they both wish this job carried on with the least expenditure of money, they are both in a position to establish cordial business relations.

We will cite an incident as to how this actually worked out. A certain large contractor, before bidding on a good-sized concrete pavement job, came to the conclusion that it would be good business to avail himself of the information that he was told could be had from the laboratory. He asked for and was given the mix that could be used on the job, using the materials from a source designated by himself. On the basis of the figures submitted he bid and was awarded the contract. The job is nearly completed, and it has been quite possible to carry on this project without any practical difference in proportions from those furnished originally. This contractor was no theorist, but a far-sighted business man out to make the job pay. There were two things that he might have done, viz., worked out his mix by the trial method, or carried out the calculation of the mix by members of his own organization. We do not insist that our figures be used. There is one thing, and one thing only, that we do insist upon, and that is that he uses no more water than he is allowed, and that the resulting concrete be plastic and workable. One of our big problems, at first, was to convince the contractor that the water-cement ratio method was workable. This called for salesmanship. Later in this paper we will give the contractor's answer as to whether or not we were good salesmen.

STARTING AND CONTROLLING THE JOB

Just before the contractor is ready to start casting, the laboratory, with the field inspection force, check the measuring devices used for the measurement of water and aggregates. The moisture in the aggregates is then determined. The quantity of water in the batch, using the laboratory figures, is subtracted from the $5\frac{1}{2}$ gallons which is allowed. If a calcium chloride solution is used, it will have to be deducted as well. We then go to the mixer and set the water regulator for the required amount that must be added. It is necessary to have the mixer on as level ground as practicable. If the mix is properly designed, and the designed quantities are carefully measured out with the required amount

of water, concrete of approximately the desired consistency as indicated by the slump test may be expected. Slight differences in the resulting slump from those desired can be rectified by slight changes in the proportions.

The following statement which we will make can be proved by statements from two inspectors, the superintendent, the foreman of the mixing gang and the mixer man.

Not once during the laying of three miles of a concrete road job was the water changed, and only once was it necessary to change the quantity of aggregates, and this was due to the fact that the grading of the aggregates was different. We wish to emphasize the above statement, for we have heard it stated many times that it was impossible to carry on a job and do this. We will also state that this job was laid on very level land. On another job laid by the same contractor, he was able to build about two miles of road without changing the mix from that furnished originally by the laboratory. This was a hilly job. Here we kept the mix and the slump constant. Owing to the mechanical construction of the water delivery system we were obliged to change the reading on the water gauge when going up and down a grade. While there was an apparent difference as far as this gauge was concerned, actually there was the same amount of water delivered in each case. No change of the amount of aggregates was made on still another job, built by a wholly different contractor, but we changed the reading on the gauge once due to a very stiff grade. We also found that the ordinary rain-storm did not affect the amount of water in a stockpile to any great extent. Should a heavy rainfall occur, we would have no objections to allowing the mixer man to cut down his water for a short time until moisture conditions came back to normal. Our inspectors would see that the mix was not changed and the same degree of workability was maintained. Probably some day the manufacturers of mixers will invent some device that will deliver a definite quantity of water under all conditions of grade, but up to the present time we have not heard of such a machine. All three of these jobs were built of imported, washed aggregates. It is our experience that concrete roads should be built of nothing but washed sand and gravel or clean crushed rock. Such a recommendation has been made to our Commissioner for all future work. The extra cost for washed material is small, but results in quality and economy of the finished product are great. When an unwashed material is used it is almost impossible to maintain uniformity of product as well as to keep it free from dirt.

INSPECTION

Without the enthusiasm and interest of our inspection force the carrying out of the method would have been difficult. Each member of this force was definitely told what was to be accomplished and the manner in which it was to be done. We tried to convey the idea to him that we had simply set up the laboratory for the time being in the field, and that the job was a laboratory experiment in which he was a vital part. It was not long before the contractor's representatives caught the spirit of the idea, and throughout the various projects even the ordinary laborer wielding a shovel took pride in helping produce the results that were obtained.

During the progress of the work we cast beams from the mix after it had been deposited on the ground. From five to seven days later part of each beam was tested. When the beams showed a modulus of rupture of 350 pounds or over to the square inch, the contractor was notified that he might have the road for his own use. This not only expedited the work but made a definite saving of money to the contractor. We cast beams also which were broken at the end of twenty-eight days. After these beams were removed from the molds, they received the same treatment that was given the pavement. Considerably higher results might have been shown if these beams could have been immediately stored in a damp closet under standard storage conditions. We were more interested in what strength developed under actual conditions than we were in the strength that might develop in an artificial manner. From the same lot of concrete, slump tests were carried out in order to check the workable conditions of the mix. On these jobs a uniform system of records were kept. On one of these projects a maximum and minimum thermometer was used in order that temperature might be recorded. It is a well-known fact that the early strength of concrete is considerably affected by temperature conditions, especially during the first twenty-four hours. During the coming year we expect to cast concrete beams using a mix similar to what would be made on one of our projects. Part of these beams will be stored under standard conditions, while the other part will be kept outdoors. We shall carry out this work during the spring and the summer. We expect by this study to learn something from the cooling effects of the spring nights and the heat of the midsummer's sun on a concrete mixture. If this study is successful it may be possible to correct for temperature in order to report results based on standard conditions.

RESULTS OBTAINED

"A man is measured by his works." This might be paraphrased to cover the problem that we are discussing as follows: The theory sounds fine but what about the results. In other words, can the same kind of concrete be made under field conditions in wholesale quantities, that a laboratory worker can put together in a small way? All highway pavement concrete in New Hampshire is designed to give a strength after twenty-eight days of 2,700 pounds to the square inch. We do not expect to get as a result concrete much stronger than this. If we wanted stronger concrete it would be a simple matter to bring it about through our design.

At the time of bidding, the cement factor that should be applicable to the job is furnished the contractor. Each day this is figured, based on the amount of concrete placed and on the number of bags of cement used. At the end of the job the average factor is calculated. The following tabulation of results has been obtained from three jobs where accurate records have been kept. The cement factor on another job is given.

TABULATION OF RESULTS

PROJECT	Mileage	COMPRESSION (POUNDS) *		Modulus Rupture *	CEMENT FACTOR	
		Designed	Obtained		Designed	Obtained
Dublin	1.77	2,700	3,135	570	1.45	1.51
Dover	5.03	2,700	2,810	511	1.40	1.43
Claremont	2.01	2,700	3,000	551	1.45	1.49
Lebanon	0.85	—	—	—	1.42	1.47

* Twenty-eight days.

From these figures it would appear that the greatest variation in the quantity of cement used was on the Dublin project, and this was only 0.06 barrel. The fact should be appreciated that our design was based on a theoretically perfect subgrade which would use neither more nor less than 35.2 cubic yards of concrete to each 100 feet of 18 feet of road. Also these figures do not allow for wastage. On the Lebanon job there was a difference in the amount of cement used on each half of the job of only 20 bags. As was mentioned before, we feel that we do not know yet all that can be learned on the subject, and therefore, we

may be able to lower the difference between the designed and the obtained cement factor figures.

So much for the contractor. It is now time to look at the results which have accrued to the State. The benefits to the State can only come in maintaining the quality desired, and at the same time save money. Reference to the above tabulations will show that we were furnished with a satisfactory grade of concrete. We did not receive 4,000-pound concrete, neither did we ask or pay for it. It is quite true that cement prices are somewhat lower this year than last, but at the most, this difference would not lower the price of a square yard of concrete more than three cents.

The following is the comparative data for costs of concrete for 1926 and 1927, as built under the supervision of the New Hampshire State Highway Department:

1926

	Square Yards	Unit Price	Total
Landaff	3,000	\$2 75	\$8,150 00
Manchester	10,400	2 65	27,560 00
Exeter	14,334	2 74	39,285 16
Total	27,734	—	\$74,995 16

Average price per square yard, \$2.74.

1927

	Square Yards	Unit Price	Total
Dover	53,096	\$2 15	\$114,156 40
Salem	13,600	2 25	30,600 00
Lebanon	8,998	2 44	21,955 12
Claremont	21,738	2 45	53,258 10
Lisbon	4,012	2 36	9,468 32
Dublin	18,644	2 55	47,542 20
Tamworth	18,556	2 23	41,379 88
Bedford	13,291	2 25	29,904 75
Total	151,935	—	\$348,264 77

Average price per square yard, \$2.291.

If 1927 contracts were let at 1926 prices, the additional cost to the State would have been \$68,150. This is a saving of \$4,729 a mile.

OPINIONS OF INTERESTED PARTIES

Earlier in this paper we mentioned the fact that part of our problem called for salesmanship. There would not be a great deal of profit accruing to the State in the adoption of the method under discussion unless the contractor used information which was available to him preceding the opening of bids. We want him to use as low a cement factor as is consistent under the conditions, and have the lower cost of cement reflected in his bid. To this end our Department encourages its laboratory to furnish the contractor with any information relative to economical mixes which he may request.

Recently we sent out a questionnaire to one of our leading contractors. This questionnaire, in its exact words and the answers, is given below. This contractor stands very high in the road-building industry. These answers are not written to flatter, but represent facts.

CONTRACTOR'S QUESTIONNAIRE

QUESTION. What was your opinion of the water-cement method of control before trial?

ANSWER. Rather skeptical.

QUESTION. What is your present opinion, and why?

ANSWER. We are in favor of this method because we are able to get a better working mix, and it also saves us money on the amount of cement used.

QUESTION. Did you know that before bidding the job the laboratory facilities of the State Highway Department were at your disposal to furnish the theoretical quantities of material that might be advantageously used by you in the manufacture of concrete on the job?

ANSWER. Yes.

QUESTION. Did you take advantage of these facilities?

ANSWER. Yes.

QUESTION. The average cement factors for your two jobs as computed by us were as follows:

Job	Designed Factor (Barrels)	Factor used (Average) (Barrels)
Dover-Somersworth	1.30-1.40	1.43
Dublin	1.45	1.51

From your experience, is this difference any greater than with an arbitrary mix?

ANSWER. No special difference from arbitrary mix, but any difference would be from the grading of the aggregate which seems to control the amount of cement used.

QUESTION. There are two men in your organization who probably come in contact with concrete operations more closely than do you yourself, viz., the superintendent and the foreman at the mixer. What is the opinion of the superintendent, of this method?

ANSWER. The superintendent agrees with the above statements.

QUESTION. What is the foreman's opinion?

ANSWER. None.

QUESTION. The New Hampshire specifications allow the use of coarse aggregate up to three inches, but contractors are not using aggregate larger than $2\frac{1}{2}$ inches. It might be possible to design a mix reducing the quantity of cement without impairing the quality of concrete by using a little larger aggregate. Is this idea feasible?

ANSWER. Yes, but the amount of stone larger than $2\frac{1}{2}$ inches would have to be carefully regulated so as not to affect the finishing. There would surely be the tendency to put in more of the large stone, especially if coming from a commercial plant.

QUESTION. From the contractor's viewpoint please give any criticism of last year's work as it applies to this problem. We would gladly receive any suggestions that you might offer for the future.

ANSWER. We feel that it is impossible to have a set formula for concrete road work, and do feel by your method of having a certain amount of cement and water, but varying the proportions of the aggregate, you get a strong concrete and save us money, and this also is reflected in the prices that are bid for the work which saves the State money.

With this testimony we will rest our case.

CONCLUSION

The study that we have given to the manufacture of concrete this year has been very interesting. It has convinced us that the water-cement ratio method is sound in principle and practicable to apply on the job. It has created a very fine spirit of co-operation between the contractor and the representatives of the State. It has given us quality concrete at a reduced cost. This lowered cost has made it possible to extend the building of this very fine type of pavement in our State.

If this paper has in a small way shown the practicability of the method we will consider it time well spent.

Discussion

QUESTION: I should like to ask Mr. Purrington if contractors in New Hampshire use the 5-ton truck, and if the modulus of rupture of 350 pounds is adequate for those heavy trucks?

MR. WALLACE F. PURRINGTON: On the Dublin and also on the Dover contracts large trucks were used, and I have been over every inch of those pavements without discovering any cracks as yet. It is

my contention that the beam test gives us the *minimum* strength, because in the pavement you have an absorption factor in the subgrade which will lower the water ratio. If you get 350 pounds per square inch in the beam, I believe that in the pavement you will get a stronger concrete. On these two jobs I have not found either corner or longitudinal cracks. I believe 350 pounds per square inch is a perfectly safe modulus of rupture.

QUESTION: What is the average time to get that strength?

MR. PURRINGTON: About seven days; that is, with a calcium chloride admixture (used integrally).

QUESTION: I should like to ask what method you use in taking samples; how deep you dig your test pits; and to what extent you guarantee the information you give the contractor?

MR. PURRINGTON: Up to the present time we have had two types of jobs, — one, making use of washed material, where we could control the mix; the other, where we simply had to approximate the mix. In our specifications we state: "For estimating purposes for highway pavement jobs a 1: 2: 3 mix may be used."

It is inconceivable that we will ever run concrete with a mix as rich as 1: 2: 3, but if the contractor wants a figure for his bid these proportions may be used.

Some contractors are beginning to come to us for the approximate proportions which may be used before they start bidding.

I mentioned a job on which the contractor bid \$2.15 a square yard, on the basis of the information we had given him. That contractor told me he was going to bid on the work and wanted information regarding the proper use of aggregates. I went with him on the day preceding the bid and looked over the logical source of supply. He was given definite information as to the mix he might use. I believe the day is coming when the contractor, either through his own engineering force or some organization like the Portland Cement Association, will obtain information prior to submitting his bid, concerning the most economical mix he may use, and then base his bid prices upon it. I told that contractor he could use from 1.30 to 1.40 barrels to the cubic yard, and he told me that this would cut his bid considerably. He had planned to figure 1.70 barrels, the same as he always did. I assured him that I was not guaranteeing him anything, but that if he would take the proportions suggested and would furnish material to the job the same as the observed material, I felt positive that he would come out all right. Data on the three completed miles of the five show a difference of .03 barrel per cubic yard over the designed figure. His

bid was 15 or 20 cents per square yard below the next bidder. The next time bids were called for, two contractors came to me for information. Next year probably there will be more, until all are seeking this useful information.

QUESTION: Do you require additional men, in the field or in the office, to make these tests?

MR. PURRINGTON: On the five mile job we have an extra man. On the rest of the jobs, "no," as it was carried on by the inspector in charge of the rest of the work.

QUESTION: Didn't it require more time to make these investigations for the contractor?

MR. PURRINGTON: No. I have practically all the data on file right now. I made the point in my paper that we would discourage in any legitimate way the use of local materials. We wouldn't probably write into the specification, however, that washed sand and gravel must be used on the pavement.

QUESTION: How often do you make test cylinders, and at about what average compression do your cylinders break under test?

MR. PURRINGTON: The compression tests are obtained from the transverse test, converting the latter results to the former by the use of the factor 5.5, which figure is given in the 1927 A. S. T. M. Proceedings. Personally, I have not much use for compression tests in the field. There is too great a possibility of specimens drying out, etc. The Association of State Highway Officials, under the direction of Mr. Mattimore, is using the beam apparatus test to determine the quality of concrete. The advantage of having the beam test carried out on the job is that both contractor and inspector can watch every phase; the whole laboratory is right there.

QUESTION: What do you think of cutting a core out for the compression test?

MR. PURRINGTON: If you are getting concrete meeting the design requirements, you have every reason to feel that you are safe, because the concrete in the pavement is undoubtedly stronger than that shown by the small beam. It is necessary in using the core-drilling machine to have special men to run it; besides, some of the specimens are sure to come in cracked, broken or out of shape, unless special care is taken in preparing them for the test. It is questionable as to whether it is a good business investment to put the money into machinery for core-drilling.

It has always seemed to me that there was no way of being certain that cylinders were necessarily representative of the actual roadway slab.

We place the cylinders right by the road. They get just the same treatment that the road gets. We make the inspection force feel that they are part of our laboratory, and try to give them a feeling of pride in that co-operation.

MR. EDWARD S. LARNED: * You have no concrete strength requirement? You have, however, a mortar strength requirement?

MR. PURRINGTON: We have no strength requirements whatever. Our only requirement is $5\frac{1}{2}$ gallons of water to a bag of cement.

MR. LARNED: I thought you mentioned an 1,800-pound strength requirement?

MR. PURRINGTON: We have a requirement that the sand be tested as a mortar to determine if the sand is sound. The 1,800-pound per square inch requirement, however, is purely arbitrary. It might just as well be 1,850, more or less. There is a definite reason why we selected 1,800 pounds, but I can't give the reason because it involves research that was carried on by another organization. We do have a mortar requirement to determine the quality of the sand, because we want clean, sound, fine aggregate, and we think this method is better than the standard Ottawa test. We haven't discarded the Ottawa test without first building up something which we consider better.

MR. LARNED: I should think that the probable actual mix could be given out so that all of the bidders might have the benefit of this information, instead of holding it in reserve for possible inquiries from an interested two, three or four. I should think it would benefit the State to do this, in the interests of economy. Of course, from the engineering standpoint that is a difficult thing to do because you can't guarantee those results. The sources of supply which have been developed are subject to variations, and the contractor must understand that, but at the same time, it does give him something a little definite to work on. A saving of .30 of a barrel of cement per cubic yard of concrete in place is a substantial saving. In the particular instance mentioned it applied to only one contractor.

I thoroughly believe in the inadequacy of the concrete cylinder tests. I don't think they indicate at all with certainty the strength that the concrete develops in the structure. There are too many accidentals, and the personal equation is an enormous factor. You may not know it, but if you want a concrete cylinder that will pull much above the ordinary, all you have to do is to omit the coarse aggregate.

MR. PURRINGTON: You reduce the water ratio.

MR. LARNED: You use the same mix, but just leave out the stone.

* Civil Engineer, 79 Milk Street, Boston, Mass.

I think the mortar requirement is an excellent thing. That really represents the integrity of the concrete. When you have good, clean sand and gravel you know that it is all right and that your broken stone can be regarded merely as ballast. It is an economizer and is not put in to add strength. If you find a concrete that is raw the chances are that you are unbalanced on the coarse aggregate side; there is too much stone. If you want to fatten the mix up, possibly you can add to the sand; or if you can't, you can reduce the stone.

MR. PURRINGTON: I am glad you brought out that point about giving out information to the contractor. When we started on this work we began like the child; we had to creep before we walked, and we believed if we could get one man to try it out that the rest would follow. We have every reason to believe that when future bids are asked for, several of the contractors will come to us for information. We wouldn't hesitate to furnish that information to our office, that they might give it to any interested contractor. We didn't want to do this at first, however, until we felt fairly confident that we could make good.

MR. LARNED: I am interested in what you said about that Dover job, because I figured that for one contractor, and had only the specification to go by. I didn't go to Dover or to your laboratory, because the contractor evidently didn't feel like paying the expense to have me do so.

MR. PURRINGTON: You could have had the information. The specification reads that the State Highway Laboratory will assist the contractor. This could have been brought about by correspondence as well as by taking the trip to the laboratory.

MR. LARNED: It is interesting to recall that the plant charge on that job, according to my estimate, with allowance for depreciation, figured approximately 20 cents per square yard. If the contractor saved .30 barrel of cement per cubic yard, he would save approximately 90 cents. So the question of capitalizing that saving on cement has to be made only on that first-hand knowledge. Now if you published that, every contractor could get the information and apply it to his bid.

QUESTION: Do your specifications state any limits for the amounts of fine and coarse aggregates?

MR. PURRINGTON: Our specification reads something like this: " . . . no more than $5\frac{1}{2}$ gallons of water to a bag of cement. The contractor shall in no case exceed 6 parts of mixed aggregates to a bag of cement. There shall be a slump of 3 to 4 inches. The sand shall show 50 per cent of the stone." That is, if the coarse aggregate should be 4 parts, then the fine should be at least 2 parts. These are all checks that can be used.

QUESTION: Have you used a hydrometer for testing the moisture in the sand?

MR. PURRINGTON: No; we have used the Chapman flask, and we are using a new apparatus designed by Stanton Walker, Director of Research of the National Sand and Gravel Association. There is a new test just developed for determining moisture, which is as follows: take a couple of handfuls of sand and place it in a flat dish; weigh this; pour on some denatured alcohol; touch a match to it; after the material is dried weigh the dish and contents again and obtain the loss in water. The Chapman flask is fragile. The Walker can proposition, also, is quite clumsy for use in the field. Denatured alcohol is easy to get, and that test seems to offer many practical possibilities for field work. It takes about seven minutes.

MR. WALTER C. VOSS:* Two points were raised which I should like to call attention to: the first is allocating a supply for the fine and coarse aggregates, which the laboratory might have access to and determine the details, so that the engineers might specify a mix arbitrarily for their concrete; and the second is the question of making cylinders — taking the stones out and getting a stronger cylinder from the same batch of concrete.

I recall a structural job in Boston where we tried to show a local engineer that he might economize by the use of the water-cement ratio. He received our advice just as a good many contractors do who read your specifications, taking the attitude that they do not give much credence to the information you could give them, because you were a laboratory technician, and that they would bid the job in the old way and see if anybody would be foolish enough to bid according to laboratory recommendations. I can only hope that these contractors will be disillusioned by the loss of one or two jobs. I do not believe it is the province of any engineer of the Portland Cement Association or any other agency to try to sell an idea to an unwilling recipient, particularly if it results in economy for him.

It happened on the particular job I had in mind that a Boston contractor who was interested in saving money by the water-cement ratio method bid the job and requested that he be allowed to bid on a known maximum limitation as to aggregate cement ratio. The concrete was originally specified by a definite ratio of materials passing certain sieves as well as a definite maximum size of stone. It so happened that this contractor knew that a good sand and a good gravel were available within half a mile of the job. A test was made of the local material and it was found to be satisfactory but at variance with the original specifications.

* District Structural Engineer of the Portland Cement Association, 10 High Street, Boston, Mass.

A saving was therefore calculated, that interested the engineer, but he was not sure in advance that he was going to get 3,000-pound concrete on that job, but was willing to "take a chance." The first three cylinders tested about 3,100 pounds, and I understand that the entire job averaged well over 3,000 pounds, at a saving of about \$3,000.

You must not forget this fact, that if Mr. Purrington were not applying the water-cement ratio in New Hampshire the cement companies of New England would be making more money. They would be selling more cement. But what we as an association representing them are interested in is a reduction of cost so that more money will be available and can be put into lower cost construction and improved quality; by this method, we believe, the quality is improved.

So I see no objection whatever to inviting contractors to get what information they can from the source of supply of this information, whether a consulting engineer, a testing engineer, the State laboratory, or any other organization able to give that information, and if a contractor can outbid others on that job by using such information at least the others will wake up. At the same time you have got to encourage competition both among the sand and gravel men and among the contractors, for if you discover a certain source of supply that will give the most economical mix, and specify that all materials shall be bought there, then that company may boost their price.

Regarding the use of cylinders, may I repeat something I have said a dozen or more times? If you take a bag of cement at 94 pounds and mix with it 6 gallons of water and stir it up into a paste and pour it into three cylinders, you should expect to get 2,800-pound neat cement paste cylinders. If you take the same paste and mix with it 1 cubic foot of sand and make three cylinders you would get 2,800-pound cement mortar, and if 2 parts of sand and 4 parts of stone were added, and you made three cylinders, you would get 2,800-pound concrete. Most people consider cement grout as water mixed with neat cement to a wet consistency, and compare it with concrete of the same consistency made of cement, sand and stone. They have never tried taking all of the stone out of such concrete and making three cylinders of what remains, to find out what would happen. They wouldn't think it possible to take a batch of concrete and single out the mortar and make three cylinders, and then single out three cylinders of the actual concrete and get more strength. It is confusing because there are so many factors linked up with it. The water-cement ratio determines the strength of grouts, mortars and concretes.

As to the Ottawa sand tests, we have come to a normal consistency

for a definite cement, and if you use Ottawa sand in comparison with the silt that Mr. Purrington used you would have to use less water than with the silt, and if less water you would increase the strength. As long as the material is structurally sound, whether it is silt or large-sized aggregate, water is the only factor controlling the strength, barring the human equation, of course; and if you pour your briquettes with a definite water-cement ratio, instead of trying to knead them, that is going to eliminate the human equation to a large extent.

The water-cement ratio which is now being applied in New Hampshire, and which has been published for the past twelve years, is a perfectly sound one and is particularly applicable to private enterprises where the supplies may come from anywhere.

MR. PURRINGTON: I have taken neat cement and sand and made it up in different mixes from neat to 1: 4, designing this for 2,000 pounds per square inch compressive strength. We got our 2,000 pounds after twenty-eight days. I made up the specimens 1: 1, 1: 2, 1: 3, but when I got to 1: 4 it was a different story. It wasn't workable. It was not plastic and we got a much lower strength.

But one mustn't forget shrinkage. The design and control of concrete mixes is very interesting and relatively simple, but its interpretation sometimes needs considerable thought and experience.

QUESTION: Do you use any automatic water control on your mixers?

MR. PURRINGTON: We use an inverted pipe of which the level can be changed by a siphon arrangement. It has to be set, however. The man in control of the mix has to change the gauge to cut down the water. We first try out the water-delivering device on a level grade. Let us say we are going to run 21.5 gallons. We put a barrel under the delivery spout and actually measure the water delivered. Suppose the mix is 1: $2\frac{1}{2}$: 3, using 6 bags of cement, 15 feet of loose and damp sand, and 18 feet of stone. We build a measured box and actually determine the quantity in the trial batch. This is always done a day or two in advance of the work. We run the sand into the box and find instead of 15 feet we are getting 16. So we keep cutting down the batch until we get the 15 feet. We do the same with the stone until we have established the amount of aggregates we are going to use. We have set our water-supply pipe, under normal conditions, for the 21.5 gallons. Most jobs start on a level, but in a couple of hours we find we have begun to change the mix a little, one way or the other. Suppose we go up a hill, and our mix, for no apparent reason in the world, dries up. Then the water pipe is no longer delivering the necessary 21.5 gallons. So

we tell the man to add a little more water in order to get back to our 3-inch slump. Then when we go down hill, if we don't make an adjustment we get a sloppy mix, so we cut down the water supply. Also if there is a heavy rainstorm we cut down our water a little; or in summer, when it is very hot and our aggregates are very dry, we add more water. We have had no difficulty in holding our slump to within 2 to 4 inches.

QUESTION: Success depends on the inspector, then?

MR. PURRINGTON: The success of *any* job depends on the inspectors.

QUESTION: Then the water ratio is not really controlled by the laboratory but by the personal equation?

MR. PURRINGTON: We consider our inspection force as part of the laboratory. We can watch the aggregate and we can watch the slump, which gives us pretty close control of the situation. If too much water is used the mix is too wet, and if too little, it will be too dry. I believe it is more practicable to handle it that way than to check the gauge every hour or so. Up to the present time there isn't any water-delivering device that I know of that is accurate under all conditions.

MR. VOSS: I might say that there is a water tank — I think it is called the "Rex" — which will deliver on almost any grade. Another form is a counter-weighted trunnion tank with a weight at right angles to the axis of the cylinder, so that the tank is always level, no matter what the grade. I don't know why development is so slow in the mixer field. There are plenty of mixers on the market today that have been paid for, but have not paid for themselves yet.

MR. MARTIN A. MORRISSEY: * With respect to the strength of the cement used in the test; you say you have to get a test of 1,800 pounds to show the sand is clean, sound and satisfactory. But I might get 1,600 pounds with one brand of cement and 2,000 pounds with another brand. Everybody would apparently get a different result.

MR. PURRINGTON: That is perfectly logical. There is no reason why you can't use 1,900 pounds if your laboratory standard for sand is premised on the use of a definite cement. For ten years we have used one brand of cement in the laboratory for all our work.

MR. MORRISSEY: If you turn down the sand, and the contractor insists on your trying some other brand of cement which is stronger, what will you do?

MR. PURRINGTON: The specification and method of test for sand definitely states what must be done.

* Assistant Chemist, State Highway Department, State House, Boston, Mass.

MR. MORRISSEY: If you test with Cement A and find a certain sand does not pass, and the contractor goes to some other laboratory which tests the sand with Cement B, and that meets the requirements, how can the Department turn it down?

MR. PURRINGTON: If you bring into our place some good sound sand and it runs 1,600 pounds on the test, you can use it, but if you use that 1,600 pounds you won't be allowed to use over 5 gallons of water with it, while for the same class of concrete $5\frac{1}{2}$ gallons of water could be used if the sand were normal.

MR. MORRISSEY: Suppose he insists on using the $5\frac{1}{2}$ gallons, as his laboratory shows the sand has passed the test?

MR. PURRINGTON: We have a statement in our specification which reads, "The material must meet the requirements of the State Highway Department." The Testing Laboratory is the official source of advice for the Commissioner for the acceptance or rejection of materials.

MR. MORRISSEY: Suppose your laboratory tests the sand and finds a strength of 1,600 pounds, and another laboratory tests it with a stronger brand of cement and gets 2,000 pounds; how are you to settle the issue?

MR. PURRINGTON: It wouldn't make any difference. If the State Laboratory says the sand doesn't go, it doesn't go.

MR. MORRISSEY: I think that is pretty tough on the sand people.

MR. LARNED: I presume your laboratory would do this: if the contractor submitted a sample of sand and a sample of the cement he proposed using, you would test the combination, and if you found it all right you would not question his using that sand with the cement he proposed using.

MR. PURRINGTON: Oh, no. I didn't say that he had got to use the laboratory cement. I said he must meet the requirements of the laboratory.

MR. MORRISSEY: I feel that your test entirely hinges upon a standard cement. If the cement varies, the 1,800 pounds has to vary. You get into the same trouble that you had with the Ottawa sand test. Every laboratory gets different results according to the cement used and the conditions in each laboratory. This is what makes the chemist appear ridiculous to practical men.

MR. PURRINGTON: We are reasonable. Give us credit for being reasonable, at least. If another laboratory declares they can meet the conditions with B cement and get the prescribed strength, we will probably try it with B and perhaps with C and D cement, before we

give the matter up. Don't think we would arbitrarily tell them that they couldn't use the sand; but in the last analysis the Testing Laboratory is final judge. We would be perfectly fair with any sand producer and go into the matter with them.

MR. LARNED: Suppose a commercial sand plant producing a washed sand failed to produce a sand that met your 1,800-pound requirement tested with the particular cement you use in the laboratory, and when tested with another cement did meet it, would you repeat your test, using the other cement?

MR. PURRINGTON: Certainly, and probably three or four other cements.

QUESTION: Would you accept any sand that would give 1,800 pounds with a cement which would pass the specifications?

MR. PURRINGTON: I would prefer to test it with the cement that we use, because it is a cement that is produced in a small mill, whereas from a large plant I might get a brand from one mill one day and from another tomorrow that would differ. That is one reason why we use one cement and keep to it. It is not better than any other, but it is our standard. Another laboratory might adopt 2,000 pounds as its requirement. Most sands we test run around 2,200 pounds and up, so 1,800 pounds is conservative. Anything under 1,800 pounds doesn't meet the test and is classed as weak.

MR. VOSS: If I furnished you a bag of the cement I was going to use on the job, and a sample of the sand I was going to use on the job, and let you use your own method of obtaining 1,800 pounds, and you got 1,800, could I use that combination?

MR. PURRINGTON: Certainly.

MR. MORRISSEY: Suppose the contractor finds out the cement you have used and for which you designed the mix and knows that he can get the same strength using another brand of cement and less of it, would you let him do that?

MR. PURRINGTON: As long as he uses $5\frac{1}{2}$ gallons of water. We do not insist on our mixes being used.

MR. MORRISSEY: Suppose in testing cements you have two cements in the laboratory both with 25 per cent consistency, and you make up briquets using the same quantities of water and exactly the same mix in each case. According to the water-cement ratio law those two briquets should show the same strength in seven days, but one comes out 250 pounds and one 400 pounds. How do you account for that?

MR. PURRINGTON: You have a fixed water ratio. The curve is based on average conditions.

MR. MORRISSEY: I mean under perfect conditions in the laboratory?

MR. PURRINGTON: That curve was based on a mixture of a lot of different cements. They were put into a machine and mixed to make a blended cement. The interpretation of results requires a certain degree of knowledge of concrete. As far as strength is concerned, if a man uses 400-pound cement we win; if he uses 250-pound material we don't win so much. We don't ask for any cement that shows over 225 pounds. If the contractor sees fit to give us a cement over 225 pounds, well and good.

MR. MORRISSEY: I have simply used two brands of cement in making up the test, but the same water-cement ratio and the same mix, and so according to the law I should get the same compressive strength.

MR. PURRINGTON: We don't say anything about strength in our specification.

MR. VOSS: It is gratifying to know that there are a lot of laboratories in the country that are making tests applying the water-cement ratio law; and it is also interesting to know they are applying something some one else has evolved. I don't think the combined laboratories of the whole United States have made half as many cylinders over a wide period of years as Duff Abrams made before he even uttered a word about the water-cement ratio. The question of the strength of concrete as applied to the strength of cement itself is a question, of course, of a slight variation in the strengths of cements. Any cement which will not pass the standard specification of the A. S. T. M. as laid down, not by the cement mills of the country, but by the engineers of the country, will not be allowed to be used in any concrete.

MR. MORRISSEY: If the New Hampshire Highway Department instead of taking the Abrams A or B curve would determine its own curve for the strength, it might find it is above Abrams curve, and so it would be possible to use more water and get the desired strength.

MR. PURRINGTON: The law states only this, that for given materials and conditions — and, let me add right here, sound aggregates — the thing that affects the compressive strength of the concrete rests entirely with the ratio of the volume of water to the volume of cement. If it is possible to increase the volume of water to get the quality of concrete you want, and thereby increase the amount of aggregate, the law allows that privilege — so long as the mix is workable and plastic.

MR. LARNED: That is admittedly impossible. You can't add 8 gallons of water to the bag of cement and obtain the same workability.

MR. VOSS: You could add 8 gallons of water to the bag of cement and add aggregate so as to get a workable mix, but it would approach harshness. Abrams A curve represents the average of all the cylinders

tested. The B curve is the lower limit of all the cylinders tested, and it has been assumed as very logical.

One thing that the water-cement ratio law has done is to show thousands of contractors and hundreds of builders that a good deal of the concrete that engineers specify as 1 : 2 : 4 and 2,000-pound concrete, has come in as 1,200-pound, and they have shuddered when they found it out.

MR. LARNED: It is a little surprising to hear the water-cement ratio now being advanced as the "water-cement law." Don't think I am hostile to it, because in 1901 I personally conducted an extensive series of tests to show the effect of water on the tensile strength and setting properties of both Portland and natural cements, and it was clearly shown that excess water lowered the strength and greatly delayed the set of both cements. The reduction in strength, however, was more noticeable at the short-time periods up to one, two, or three months, and the difference was not so marked at the later periods.

The publicity given to the water-cement ratio theory advanced by the Portland Cement Association has done more than anything else to arouse architects, engineers, and contractors to the dangers and evils of excess water. This information was put before the public in much shorter time and more effectively than could have been accomplished in any other way, and I have given them full credit for the results achieved, if not fully subscribing to all of the ideas effecting the use and proportioning of the fine aggregate.

About two years ago, or a little longer, when committee C-9 were working to determine the extent and cause of variations in the mortar test results, it was generally agreed that these variations were largely the result of the personal equation, and I suggested to a member of this committee that the personal equation be eliminated by discarding the so-called normal consistency test and resorting to a mix sufficiently fluid to fill the molds without pressure or working, and yet short of a consistency that would permit of segregation, and I have been told that tests conducted along these lines, by both experienced and inexperienced operators, have shown very uniform results. In testing natural or commercial sands, this method would also bring out certain characteristics of the sand that the normal consistency mix never develops.

I think we should have a sand specification including a strength requirement expressed in pounds per square inch and not based on any comparison with Standard Ottawa sand. Commercial sands differ widely in their values as a mortar ingredient, and for economical and structural reasons the sand-cement ratio is very definitely limited, and

since the strength of concrete is primarily governed by the strength of the mortar or binding medium, we should make it possible to select the sand that would produce the desired results.

Standard Ottawa sand was prepared primarily for use in testing cement, to determine the uniformity of the cement, and was not intended as a standard by which commercial sands were to be judged. Furthermore, the A. S. T. M. Standard Specifications for Portland cement fix the test proportions at 1 part cement to 3 parts Ottawa sand by weight mixed to "normal consistency." We do not use commercial sand on high-class work in such proportions or of any such consistency, so the comparison is not fair and not what we need. We have a strength requirement for Portland cement tested with Ottawa sand, and pass it if it pulls 225 pounds per square inch at seven days; why not have a test requirement for the cement and commercial sand to be used on the job also, based on a rational consistency comparable with practical working conditions? The true economic value of a given cement and a given sand would then soon be determined.

MR. PURRINGTON: I don't know whether I agree with you. The more I study sands the more uncertain I become in my own mind, provided the sand is clean, that its strength is so very important as an element in concrete. At the present time I am having some cylinders made up of one of the so-called weak sands, and the strengths are coming pretty near the theoretical. You have four things in there, and sand isn't any more important than the others. The coarse aggregate is important, the water is important, the cement is important. If the sand is clean what great difference does it make whether it shows 2,000 pounds or 2,500 pounds per square inch compressive strength?

MR. LARNED: You say it makes no difference whether it shows 2,500 or 2,000 pounds. It makes a difference whether it shows 1,500 or 2,000 pounds, doesn't it?

MR. PURRINGTON: I say "above the minimum" we have arbitrarily set it doesn't make any great difference. You can make as good concrete as far as strength is concerned from silt as from sand, if you are willing to pay the bill. The shrinkage characteristics of the rich mixes would have to be considered. With $5\frac{1}{2}$ gallons of water you can get the same strength, but look at the cement factor it would require!

MR. LARNED: What we need above everything else in the making of concrete is common sense. I was called in on a job recently where they were getting 1,100, 1,200, 1,300, and 1,400 pound concrete and they wanted 2,000, and couldn't see why they weren't getting it. The

cement tested all right and the aggregates had been tested and approved. It was nothing of a job to push that concrete up to 3,000 pounds, but it is only fair to say that the test of the aggregates did not reveal the actual working conditions and they had to be changed.

If you are going to have proper concrete you must have cement enough to fill the voids in the mortar, and enough mortar to fill the voids in the stone, and the New Hampshire specification virtually admits this rule.

Granted that the Ottawa sand requirement was empirical, there was nothing better. You knew that there was a sand that ran very uniform because of its gradation and soundness. If we are throwing that test aside I believe we should write a specification for sand. It is coming, largely through the instigation of the Portland Cement Association. The A. S. T. M. hasn't adopted any standard. The first tentative requirement was 75 per cent, and later it rose to 100 per cent, largely through the influence of the Portland Cement Association, but that brought about difficulties, because while well-graded sand will compare favorably with Ottawa sand, if you run into a fine sand, or if silt or material above the 100-mesh sieve be present, the test results will be lower. If under the sand specification you can't find a local sand that meets it, you can at least obtain the structural requirements by enriching it with more cement, and silt should not be used in any mix.

MR. PURRINGTON: That is exactly what we do. If we find that the sand won't meet our 1,800-pound requirement, I say you can use it with 5 gallons of water. That means nothing in the world except to increase the cement.

MR. MORRISSEY: I think the chief trouble with the present method of testing sand is that it only takes account of one variable — namely, soundness — when there are actually two variables, — soundness and grading. Suppose that a sand is sound, but on account of its fineness will only test 90 per cent. It is only necessary to use a little less sand or a little more cement to make good concrete out of it. Good concrete can be made out of such sand, but you must change the mix from 1: 2: 4 to 1: 1.8: 3.8. You will get the same strength and quality of concrete for practically the same cost, and this is the most economical thing to do in many cases. It is not necessary to use Abrams curves or the water-cement ratio.

DESIRABLE AND REASONABLE TRAFFIC REGULATIONS FOR GENERAL USE

BY E. W. JAMES *

(Presented before the Affiliated Technical Societies of Boston, April 18, 1928)

IN the course of the last ten years the civil engineer who has made highway work his specialty has found that a new phase of highway activity has been rapidly growing in importance. We were formerly concerned with highway construction and maintenance; we are now concerned with highway construction, maintenance and operation, and by no means the least of these activities is highway operation. While highway transport is acquiring more and more the characteristics of railroad transport in many of its aspects, highway transport is characterized by, and must be protected in, retaining the element of flexibility which makes it of such outstanding importance. We have a relatively high-powered vehicle which does not operate on individual trackage. We place at the throttle of this vehicle any person with ordinary intelligence. The manufacturer is constantly striving to widen his market, and cheapen the equipment to a point where it will be available to smaller and smaller incomes and a constantly extending use.

The automobile is rapidly becoming an expression of American life. Freedom of movement, like freedom of speech, freedom of the press and freedom of worship are fundamentals of American liberty, and the outstanding instrumentality of freedom of movement in America today is the individual automobile and the commercial truck. Thirty years ago, when our automobile registration was 4,600, we were figuratively still sitting at the feet of the French road builder, taking lessons in the testing of materials, the drafting of specifications and methods of construction, and no State in the Union had an improved highway entirely across it in any direction. Since then we have become the foremost road-building nation of the world, and our progress in the science and art of highway construction has been so great that today all the world is turning to the United States for ideas and guid-

* Bureau of Public Roads.

ance in the expansion of their own older highway systems. The automobile industry has grown until it has produced in excess of 4,000,000 vehicles in a single year, to accommodate which on a 15-foot headway would require over 21,000 miles of highway. To construct, maintain and operate highways under such pressure is a matter of the greatest national urgency. With respect to the operation, with which we are particularly concerned, our problem is twofold, — to make adequate provision for what we have in the way of transport, and to take preventive measures against a national jamb in the future.

If funds are forthcoming, the highway engineer can take care of construction and maintenance. The highway-building industry is today equipped to take care of any probable emergency in this direction. The serious problem lies in the field of operation. As conditions exist it is more dangerous today to drive a car than it is to have typhoid or diphtheria or both, and to drive a car for ten years is more dangerous than to be called upon once in ten years to serve in an expeditionary force in a great foreign war. In the last ten years we have lost by death in automobile accidents about 30,000 more than the entire losses in battle, by disease, suicide or accident during the period the United States was engaged in the World War.

The railroads have found it necessary to establish elaborate and exact operating regulations. Railroad engine drivers are highly skilled men of mature years, physical soundness and having good judgment. Our great problem is to establish an equally efficient set of operating rules, applying them to the drivers of automobiles and trucks, and do this in a manner which will not destroy the outstanding advantage of motor transport which is its great flexibility.

I submit to you two fundamental principles which I think must apply in such an effort; these are the rule of uniformity and the rule of reason.

RULE OF UNIFORMITY

I believe the first rule is generally accepted. We have had the Hoover conference on street and highway safety prompted solely by an effort to induce unified action by the several States in all matters pertaining to highway traffic, including traffic regulations. Out of this conference has grown the Committee on Municipal Traffic Regulations, which is now actively engaged in formulating the details for the regulation of traffic in municipalities. The Association of State Highway Officials has undertaken to promulgate a uniformity of highway marking, including a variety of caution and danger signs. As all of this

work has progressed it was found that there existed so great a variety of regulations, rules of the road, and methods of conveying instructions as to amount almost to a chaotic condition. In the three and a half years since the meeting of the first conference on street and highway safety there has been a decided change for the better, but much remains to be done. The immediate accomplishment has been the general acceptance of the rule of uniformity. When a man can drive in any city or in any State with the same confident familiarity with driving requirements that he possesses with respect to his own community, I believe much will have been done to reduce the needless stream of accidents that now flows along with our highway traffic. In admitting that the application of this fundamental rule is difficult and will be slow, I speak from a full and wide experience, but past performance is encouraging, and I believe that we may look for the relinquishment of pet ideas, of the desire to be different, and of the tendency to enforce unique restrictions, and for the ultimate adoption of regulations which may be everywhere communicated in approximately the same form and enforced in essentially the same way.

RULE OF REASON

The rule of reason does not yet occupy so sound a place in our public handling of traffic problems. This always characterizes the rule of reason when applied to any activity. Devising a test of reasonableness is the very first difficulty. Shall we, for instance, base our test of reasonableness on speed or on congestion? In order to avoid the latter, shall we throw down the bars to speed? In order to avoid speed shall we aggravate congestion?

In the last three or four years there has been a pronounced tendency in State traffic laws and local regulations to permit, or even encourage, high speeds. On the other hand, some investigators have shown that a traffic lane will deliver per hour more vehicles operating under safe conditions and at a speed of 15 miles an hour than at any higher speed. In some cases the whole question is dodged by an effort to control reckless driving only, whether this is required in speed or in handling the car. I am of the opinion that a substantial per cent of our accidents today are the result of overspeeding with respect to the conditions existing. We can imagine congestion, but it is difficult to imagine a serious automobile accident if all cars were operating at six miles an hour. The fact that 63 per cent of the accidents in Connecticut occur on good road surfaces, that 59 per cent occur in daylight,

that 78 per cent occur in clear weather, that 38 per cent occur on a clear course, and the further significant fact that the rate per one thousand accidents for drivers under twenty years of age is three times that of drivers over thirty and four times that of drivers over fifty confirms me in this opinion. This is further supported by the fact that the driver is considered to blame in 74 per cent of all cases.

The adjustment to be made in determining the rule of reason as applying to speed and congestion is to fix after adequate study what will reduce congestion to the lowest amount obtainable with the greatest safety. If this results in relative congestion on our streets and highways, then the remedy is other routes or wider routes. This is the sound way to take care of all conditions which exist, and indicates the preventive measures for the future to which I have already referred.

TEST CAR USED

Recent surveys have been made in the vicinity of Cleveland, Ohio, and in the city, where there exists on different routes a great variety of traffic, and where there is at some points an excessive and annoying congestion. A space-time recording apparatus was used for determining changes in speed and distances covered. A careful census of total traffic was made on all the routes studied. In operating the test car, carrying the space-time recorder, the experiment required that the operator put the car into the stream of traffic and keep it there as nearly as possible in coincidence with the general flow of vehicles. If one car passed him, he was instructed to pass one car, thus retaining his relative position in the line of traffic, but he was not to weave about with the purpose of gaining advantage in position so that he might increase his speed. He deliberately operated with the general flow of traffic. A recorder kept notes of events during the run, and the figures which I have to submit are those which were produced where conditions of congestion were just avoided. It was found that where the traffic on a 2-lane road was at the rate of 3,000 per day (twenty-four hours) an average speed of 36 miles was possible. With 4,000 traffic per day a speed of 34 miles was attained; with 7,250 a speed of 25 miles was recorded. On a road which was unnecessarily wide for two lanes, but hardly qualified as a 3-lane road because of parking conditions, a daily traffic of 8,500 vehicles permitted a speed of 28 miles, and a daily traffic of 12,250 a speed of 24 miles. If this is considered a 3-lane road it will be seen that these values fit in exactly with the previous figures for a 2-lane road on the basis of traffic per lane. On a 4-lane route the fol-

lowing conditions were observed: When 12,000 vehicles per day were passing, a speed of 29 miles was possible; with 17,000 vehicles the necessary speed dropped to 28 miles; with 29,000 vehicles the speed was 24 miles an hour; and with 32,000 the speed was $23\frac{1}{2}$ miles per hour.

Studies were made on other routes with somewhat greater refinement with respect to the traffic census. On a certain 6-lane road with 1,300 vehicles per hour a speed of 16 miles was attained; with a traffic of 1,700 per hour a speed of 14 miles was indicated by the tests. A similar more refined study on a 4-lane route covering 1,300 per hour indicated a speed of 16 miles per hour, and one covering 1,500 per hour the speed was forced down to 9 miles. These studies, while indicating higher speeds for the most part than those resulting from a mathematical study such as that made by Dean A. N. Johnson, clearly show, nevertheless, that a given traveled way will carry more vehicles at a lower speed under average conditions of operation.

The accidents reported in the city of Cleveland and shown on a spot map indicates that along the routes where the above figures have been secured the relative safety of driving is what may be referred to as normal or average. With the speeds and the traffic indicated the rate of accidents per 1,000 vehicles was neither substantially above or below the rate on other thoroughfares.

This still leaves us in doubt as to whether a further restriction of speed would or would not reduce the accidents on these particular routes, but the studies are reasonably conclusive that the speeds were not so low as to be the cause of congestion, inasmuch as the capacity of the routes was continuously increased down to the lowest speed indicated. The result of these particular studies, therefore, would appear to indicate that speeds above 20 or 25 miles per hour are not necessary to reduce congestion. If carefully coincident studies could be made to determine whether accidents on these particular routes or other routes similarly studied are at a greater rate for higher speeds, it will probably be possible to fix upon a reasonable speed which will reduce accidents to a minimum and at the same time cause no congestion and maintain the capacity of the route at as high a point as can be conceded to the demands for saving time. Whether a similar speed limit should be fixed for the open highway is a question which should receive further careful study along similar lines, and in coming to a conclusion it should be borne in mind that one of the purposes of present regulations is to prevent future traffic difficulties. It is therefore better to maintain relatively low speeds not absolutely required by route capacity at this time in order to avoid the necessity of re-educat-

ing the public to low speeds in the future after they are thoroughly accustomed to high speeds.

RED AND YELLOW LIGHTS

There are several other matters which are still in the debatable zone when we apply our rule of reason, and conspicuous among them is the use of red and yellow lights. Red is almost universally recognized on the highway as a stop light. The Association of State Highway Officials, however, has adopted a stop sign with a yellow background, and the question of red or yellow for automobile tail lights is still unsettled. It occurs to me that there is a rather nice distinction that can be made with respect to the use of red or yellow which may be stated somewhat as follows: red signifies to stop and to remain stopped until the signal changes or some other instruction is given to proceed; yellow signifies caution, and if a yellow sign instructs traffic to stop, it indicates that extreme caution is necessary and that traffic should stop, but may then proceed past the stop sign without change of signal or other instruction when the driver is assured that he may safely proceed. This formula appears to come nearer fitting all of the conditions logically than any other I have heard. It permits the continued use of red tail lights, red lanterns on fixed obstructions, and yellow boulevard stop signs where the intersection is not automatically or otherwise controlled.

Where control lights are operated at an intersection the color cycle also varies. According to present practices it is "Red-Yellow-Green-Yellow" in some cases, and "Red-Green-Yellow" in others. The use of the yellow interval between the red and green is in question. The present trend of opinion, however, appears to be in favor of the "Red-Green-Yellow" cycle, and the reason for this appears sound. On the open street the yellow should flash, while the red still shows on the closed street; then when the yellow goes off the red goes on the formerly open street; the green should at the same instant come on the formerly closed street. This sequence gives warning on the open street that the red is about to flash, and provides opportunity for the intersection to be cleared before the green goes on the intersecting route.

PAVEMENT MARKINGS

There is a growing tendency to use pavement markings, and a word should be said regarding more particularly the use of the continuous white line. It appears desirable that the continuous white

line should be used only where it should never be crossed. This is a simple rule which the public can easily learn even if they disregard it in practice. Such a white line is the best possible witness in case of an accident. The man whose car is on the wrong side of such a line has no justification whatever. If such continuous lines are used where they may be crossed and where they may not be crossed confusion will always exist in the minds of drivers. Practice in the use of the continuous white lines is gradually crystallizing for the following uses:

- (a) Centerline on a curve having a radius of less than 600 feet.
- (b) Centerline on a grade steeper than 6 per cent.
- (c) Centerline on vertical curves where the clear sight distance is less than 500 feet.
- (d) Traffic lanes on streets wide enough for three or more lanes, where direct approach to certain critical areas is necessary.
- (e) Street-car landing areas.

Where white lines are considered necessary to indicate the boundary of pedestrian cross-walks, of vehicle turning limits at street intersections, at street-car clearance limits at turning points, or to indicate parking space, broken lines should be used.

Considerable difference of opinion still exists with respect to the time and method of making left and right turns at controlled intersections. Left turns are sometimes made on the outside of the intersection; sometimes closely around the center of the intersection. Right-hand turns are sometimes permitted and sometimes not permitted against the red light on the closed street. These two sets of conditions must be handled together.

In the first place, if we are to adhere to the significance of the red light, a right turn should not be made against it. If this is established, then the left turn at the center of the intersection will tend to obstruct traffic more or less seriously whenever vehicles waiting the right turn are standing close to the intersection. Therefore, if right turns against the red light are prohibited, left turns should be made on the outside of the intersection. This relation appears to be the soundest solution. It can be used on both wide and narrow streets where control is automatic or by police direction, and it throws all vehicles waiting both the left and the right turn over to the extreme right-hand side of the approaching street and intersection. Any other combination appears to have some greater disadvantages.

I have confined myself to those details of general traffic control which are at the present time most in dispute. Other details which are subject to a variety of adjustment are controlled by local situations

existing. For instance, the one-way street has its supporters and its opponents, but after all it is a matter of the physical routing of traffic rather than a rule of the road. The parking question is a very serious one and widely and vigorously disputed, but it is a purely local question in every instance, and often it is local to individual streets or to blocks in a single street.

Such questions, however, are of the greatest significance in pointing the way toward those preventive measures which must be seriously considered if we are to meet future conditions which now appear probable. These preventive measures have very wide ramifications. They involve not only the question of routing and of parking space, but the details of highway and street design, and ultimately of city and regional planning. In all of these directions some work is being done, but we are not yet ready to draw definite conclusions with respect to many of the details. Highway engineers are perhaps more nearly in agreement on details of design to accommodate traffic than traffic directors are with respect to one-way streets or the parking privilege. And those devoted to city and regional planning are carefully studying the questions of building height and capacity, street layouts, decentralization, and the segregation and grouping of various business activities. All of these matters are involved in preventive measures for the future, which will make possible the continuation of urban growth and development without burdening such communities with exorbitant expenditures to overcome chaotic and impossible traffic conditions.

Specifically, at this time we are in need of information regarding the traffic density on 2, 3 or 4 lane intersections when automatic signals should be introduced, and the further point in traffic density when police control should be adopted. There are still to be found many who believe that traffic moves more rapidly and even more safely when it is permitted to make its own way through intersections. Undoubtedly traffic control has been installed where not needed. This is because we do not know for any given case what the critical points of capacity are. This should be studied.

Further studies should be made regarding the increased efficiency of a highway due to the introduction of rotary intersections or grade-crossing separations. Theoretically a grade-crossing separation should give us an increased efficiency of at least 50 per cent. It is probably more than that. Such a large saving may warrant the expenditure of much greater sums for this kind of work than we have believed justifiable heretofore.

Studies regarding the detailed design of rotary intersections are

imperatively necessary at once. The Bureau of Public Roads is now considering a rather wide study of this last matter, and it may be expected that within a reasonable time some data much more valuable than any now available will be in hand.

The use of this material is going to be necessary in the near future, for it requires but little imagination to picture the impossible condition which will result if we depend entirely on methods of immediate control for the solution of all possible traffic problems, and reject those preventive measures which promise so great an advantage for the future.

RESURFACING WORN AND DEFECTIVE PAVEMENTS

BY CHARLES F. KNOWLTON,* MEMBER, BOSTON SOCIETY OF CIVIL ENGINEERS

(Presented before the Highway Section, B. S. C. E., December 28, 1927)

THE subject of "Resurfacing Worn and Defective Pavements" is always an interesting one to engineers and highway officials, and particularly at the present time when so many of our pavements are beyond the stage of ordinary repairs and must be rebuilt or resurfaced to meet the demands of motor traffic.

The problem to be solved is, how can an old pavement be resurfaced in a satisfactory manner without wasting the good material already incorporated in it and which has been hammered by traffic until it is settled and unyielding?

The taxpayers who have their money invested in a pavement dislike to see it torn up and thrown away a few years after being built, and they have a right to expect a large amount of salvage in resurfacing.

I have been asked by your chairman to give costs of the various kinds of pavements. In doing so I expect the figures will be criticized severely. Costs depend on character and depth of excavation, thickness and mixtures of foundations, character and sizes of materials, proximity to the work, and many other causes, but the figures given represent fairly average costs in this vicinity.

Pavements can be divided into two classes, — permanent and semi-permanent. The permanent pavements are those that are supposed to last longer than ten years, or beyond the term of the bonds the law allows to be issued. Granite block on a gravel base, grouted granite block, brick and wood block, and asphalt, all on concrete bases, and plain and reinforced concrete are types of permanent pavements. The semi-permanent pavements are those that are supposed to last longer than five years, and for which the laws allow only a five-year bond issue, and the specifications of which must be approved by the Massachusetts Department of Public Works, Highway Division. Bituminous concrete, bituminous macadam, plain macadam, amesite, kyrox, bitu-

* President, Simpson Brothers Corporation, Boston, Mass.

lithic and simasco, when not laid on concrete bases, are types of semi-permanent pavements.

Up to the present year the common practice of treating the above pavements after the surfaces had got beyond the stage of ordinary patching repairs was about as follows:

PERMANENT PAVEMENTS

Granite block on a gravel base costing about \$5 per square yard would not wear out, and would not need resurfacing except for the settlements which occur on account of a poor soil foundation or on account of trench settlements. The blocks are relaid where these settlements take place, and often in a careless manner. In the course of a few years there have been so many of these settlements and so much careless patching that the surface is very irregular and repairs are imperative.

In some cases the entire pavement is taken up and the blocks relaid on a fresh gravel base and clean sand joints for about \$1 per square yard. The condition then is far from satisfactory. Until the sand filler has been thoroughly driven into the joints it proves very dusty in dry weather and muddy and slimy in wet, and the blocks are again liable to settle in places and the surface become as rough as before.

Cold patch asphalt mixture is sometimes used to fill depressions, but this is only a temporary repair. Tar and asphalt mixtures have been tried in resurfacing the entire surface, but few have been successful. In some cases the top has been ground off and pulverized under the impact of traffic. In some cases the mixture was too soft and the top pushed and shoved into waves. In some cases the top was too thin, and the hammering of traffic made the surface as irregular as the blocks underneath. The method most successful was to level up the depressions in the block pavement by some bituminous binder, and then lay a regular asphalt top 2 inches thick at a cost of \$2 per square yard, the weight of the top being depended on to hold the surface in shape. In all these cases, however, there is no bond between the wearing surface and the smooth granite block; moisture gathers and freezes, the top slips and creeps, and soon resurfacing is needed again.

The only other method of salvaging a granite block pavement is to remove the blocks and reclip or recut them to a smaller size of 6 to 8 inches long and 4 to 4½ inches deep. These are then laid on a concrete foundation and the joints filled with cement or pitch at an average cost of \$4 per square yard.

A granite block pavement on a concrete foundation with cement grouted joints, costing about \$7 per square yard, is the most permanent pavement known today, and if properly repaved over trench excavations should never need resurfacing. If this pavement should ever need rebuilding, the concrete base would be the only salvage, as new blocks should be used.

Brick and wood block pavements, costing from \$5.50 to \$6 per square yard, are always laid on a concrete base in this locality with a sand, cement, or asphalt filled joint. These pavements often need resurfacing, the bricks chip and crumble on their edges, and the wood swells and buckles, all tending to make an uneven surface. Oftentimes the presence of car tracks, man-hole and catch-basin covers prevent resurfacing with asphalt of sufficient thickness to stand the traffic, and usually these pavements are rebuilt, — the brick or wood removed and discarded, and new brick or wood or an asphaltic concrete laid on the old concrete base, that being the only salvage, the cost ranging from \$3 to \$4 per square yard.

Concrete pavements 6 inches thick, costing \$2.50 to \$3 per square yard, and reinforced concrete pavements, 8 inches thick, costing \$3.50 to \$4 per square yard, are of quite recent construction. The latest types show no need of resurfacing, but the earliest types of plain concrete are badly cracked and worn at the joints, and in some cases disintegrating. These are being repaired by filling the cracks and worn places with cold patch mixtures or hot bituminous material. These pavements cannot be rebuilt without removing and wasting the original material. There is no salvage whatever. That means an entirely new pavement of some type.

Resurfacing with a bituminous mixture has so far failed to be at all permanent or satisfactory. The surface of the concrete is so smooth and glassy that no bond or adhesion is obtained. The presence of car rails, curbs and structures in the street in some cases prevents building a new wearing surface, unless it was wisely provided for in the original construction.

The hard smooth surfaces of the permanent pavements cannot be resurfaced with Portland cement concrete unless a change of grade will allow at least a thickness of 4 inches.

Bituminous concrete is the only material used so far with any degree of success, but must be laid not less than 2 inches thick, with no feathering or thinning at the edges, which will cost \$2 per square yard.

Asphaltic concrete or sheet asphalt laid on a concrete foundation at a cost of \$3.50 to \$4 per square yard is a type of permanent pave-

ment that is most easily resurfaced. It often becomes worn along car rails and lines of traffic by the action of tire chains, when ruts in snow and ice, filled with water, concentrate the wear. These worn places are repaired by squeegeeing a coat of hot asphalt over the surface. Drippings of oil from motor vehicles sometimes cut and soften the asphalt surface, and the hammering of traffic causes depressions and ridges. Moisture gathers between the concrete base and asphalt top, causing disintegration, and often the top slips on the base and forms in waves. Burnt or overheated asphalt mixtures will cause disintegration of the surface. These defects are commonly repaired by cutting out the worn or defective places and new material laid. Very seldom is it necessary to resurface the entire pavement, as repairs can be so easily made and a good bond obtained with the adjacent surface. Sometimes the entire surface is given a seal coat of hot asphalt, but this is of doubtful permanent value. It has a tendency to enrich and soften the original mixture and cause it to become wavy.

SEMI-PERMANENT PAVEMENTS

We now will consider the semi-permanent pavements. Nearly all of these have asphalt or tar incorporated in them in various forms and mixtures, giving them for a few years a smooth, inviting surface. They are laid on gravel, macadam and loose broken stone foundations, and defects are more often caused by frost action and settlements of the base than from other causes.

The wearing surface of the various asphalt concrete mixtures is very seldom more than 2 inches thick, and being so flexible and pliable the surface often reflects the inequalities of the foundation, and resurfacing is inevitable.

The cost of the various types of bituminous concrete is about \$2.50 per square yard. When they need resurfacing the usual method is to remove the entire 2-inch top and lay a new surface, and the cost is generally as much as for the original pavement. Practically no salvage is received from the old material.

Bituminous concrete is a combination of asphalt and mineral aggregate of predetermined proportions, heated and mixed together in a mechanical mixer and laid while in a heated state.

Bituminous macadam is a combination where the mineral aggregate is first placed in position while cold, as in a macadam road, and then coated by spraying or pouring hot liquid bituminous material over the surface which penetrates into the voids to an extent depending on the

size and compactness of the stone, but seldom over 2 inches. The favorite type of bituminous macadam is usually 6 inches thick, laid in two courses, the lower 4 inches bound with sand or stone dust, and the top 2 inches penetrated with bitumen, costing \$1.50 to \$2 per square yard.

Many of the old type of water-bound macadam roads have been treated to a surface coat of hot bituminous material. This is a preventive of the raveling of the macadam, and serves also as a dust layer.

The surface of these semi-permanent pavements often settles, the stones ravel and holes develop. The unequal application and penetration of the bituminous material cause fat places to appear which are pushed or shoved into ridges or waves, making resurfacing imperative after a few years. If the surface is not worn out, but only rough, the usual method of resurfacing is to plough or scarify the old surface, shape it anew, and apply a new coat of bituminous material. The results are far from permanent or satisfactory.

Without going into too much detail you have been told of the different kinds of pavements, their costs, causes of defects, and methods of resurfacing formerly used.

All pavements in course of time arrive at a point when resurfacing is necessary. The question is not *Why!* but *How!*

The problem that has bothered us is solved at last by the introduction into New England of the vulcanizing process of resurfacing pavements.

VULCANIZING PROCESS OF RESURFACING

Hearing of the wonderful success of a patented heater in renewing asphalt pavements in the large cities of the South and West, a progressive contracting firm of Boston sent representatives to various cities and thoroughly investigated the process, the result being that they introduced into this section of the country the Greco Pavement Heater. The purpose of this heater is to heat road surfaces with a blast of hot air so that a new surface can be welded or vulcanized on it with proper adhesion.

You heat iron to weld; you heat all the materials in an asphalt mixing plant to make them adhere together; and you heat soft rubbery materials to vulcanize or stick them together. So if you want to place hot asphalt on to any kind of surface and make it firmly adhere, why not heat and clean that surface — the same principle you would adopt in a mixing plant?

Results obtained for many years by southern and western cities

in resurfacing all kinds of pavements have proven the principle to be correct and the results permanent, satisfactory and economical.

The process is as follows:

First. — You must have a firm foundation to build upon, or, in other words, the pavement you propose to surface must have had years of travel and become beaten down and settled so that it is hard and unyielding.

Second. — Clean the old surface of loose dirt.

Third. — Drive a blast of hot air from the Greco Pavement Heater until the surface is heated to a temperature of 250 degrees.

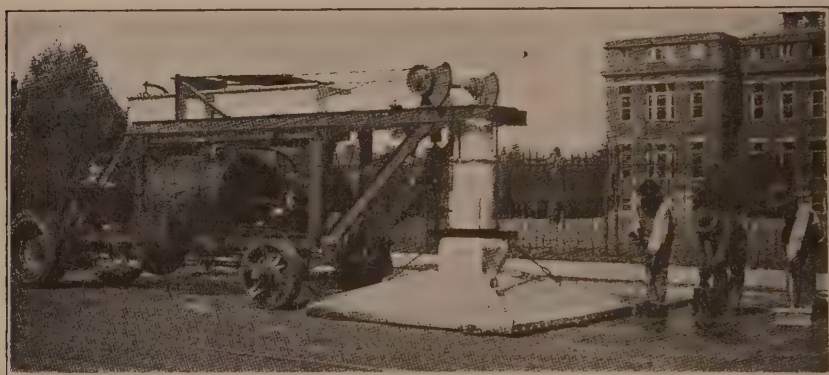


FIG. 1. — PAVEMENT SUPERHEATER

Fourth. — Apply a priming coat of hot asphalt cement to the clean heated surface.

Fifth. — Lay a wearing surface of hot sheet asphalt mixture.

The Greco Pavement Heater is mounted on a Fordson chassis, and has a heating chamber on top where the air is heated by a fuel oil flame. The hot air is then driven by a fan through a pipe to the hood. This hood is 8 feet square and rests on the pavement surface. Thus no injurious flame can touch the surface. The blast of hot air can be regulated as to heat, but a temperature of 750 degrees is sufficient to melt and soften an asphalt surface, or to heat sufficiently a hard or monolithic pavement, in a minute or two. When the area of 64 square feet is heated the machine moves along. In this way it is possible to cover 800 to 1,000 square yards in a day.

The asphalt used in the priming and sizing coat and in the plant mixture should be pure asphalt cement having a penetration of 50 to

60 at 77° F., and the best results are obtained by using a sheet asphalt mixture as specified by the American Society of Municipal Improvements.

Many types of pavement were resurfaced the past summer by this vulcanizing process.

One type was a 6-inch, penetrated asphalt macadam. This had a very rough surface, but made an excellent foundation to build upon; no part was dug up and wasted. It was cleaned of loose dirt, heated by the Greco, and the old asphalt melted, scraped, and broomed off until the surface stone was clean. The priming coat of hot asphalt cement was then applied by a squeegee machine or mechanical spreader. The holes and depressions were then filled with a hot, close asphalt binder and rolled in until a uniform contour and grade was obtained. A sheet asphalt mixture was then spread, raked and rolled to a uniform thickness of 1 inch. A mineral dust was then broomed over the surface. Portions of this street had a granite block pavement for the full width, and had a granite block brow along the car tracks. This granite block was covered and treated in the same manner as the asphalt macadam. The progress of this work was at the average rate of 950 square yards per day. The day's work being opened to travel twelve hours after construction, there was practically no interruption to traffic. In many places, to secure a smooth uniform surface, the wearing surface was carried out to a feather edge, and six months of heavy usage showed no defects whatever. A fine asphalt pavement good for at least fifteen years was thus obtained at one-half the cost of a new asphalt macadam.

Another type was a water-bound macadam which had been surface treated with tar for many years until the surface was like a rough elephant hide, and was 3 inches thick in places. This surface was melted and scraped off, leaving a clean, hard foundation upon which priming coat, binder and sheet asphalt surface were laid as in the first type.

Another type was an old sheet asphalt pavement, worn out and patched in many places with cold patch material. This was cleaned, heated and the old material roughened up by rakes, showing considerable life remaining in the old asphalt. The dry hard surfaces were coated with asphalt priming coat to get proper adhesion, but the live asphalt was only loosened up to receive the hot top, the adhesion or bond being as perfect as in new work.

Another type was a pavement of asphaltic concrete, perhaps imperfect in construction, but certainly worn out. It furnished a good foundation, however, and the regular method of vulcanizing produced excellent results, just as good and permanent as a new pavement.

Another type was a 6-inch concrete pavement that had cracked,

been dug up in many places by public service corporations, and imperfectly repaired by cement and cold patch mixtures. After cleaning this surface of loose dirt by brooms and flushing with water, it was heated by the Greco, which was followed closely by an air compressor. This compressed air blew all the particles of dust from the pores and joints of the concrete, so when the hot priming coat was applied it got an unusually firm grip. A little close binder was used at the old joints and patches. The sheet asphalt wearing surface on this job was $1\frac{1}{2}$ inches thick. The results under tremendous traffic have been satisfactory and should last as long as any asphalt surface laid on a concrete base.

These few examples of methods with the results obtained convince us that any kind of a surface that is firm and compact can have a new asphalt surface vulcanized on to it that is as good as a new asphalt pavement laid on a concrete base, and the cost will only be from \$1.25 to \$1.50 per square yard.

Fifty years ago, when sheet asphalt pavements were first laid on Portland Cement concrete foundation, they were generally $1\frac{1}{2}$ inches thick. Hot weather softened this malleable surface sufficiently to cause it to slip or shove into waves, for the reason it was not attached or bonded to the concrete. As a solution of this problem a binder course $1\frac{1}{2}$ inches thick was first laid and the $1\frac{1}{2}$ -inch sheet asphalt surface laid on that, giving a total thickness of 3 inches. This method provided weight enough to hold the surface in place, but it still was not bonded to the concrete. Afterwards, asphaltic concrete, bitulithic and Topeka mixes were introduced and laid 2 inches thick on concrete foundations, but these do not adhere to the base any better than the sheet asphalt. Take up any of these pavements and you will find the under side of the asphalt worn and polished, and the concrete surface also polished smooth by the slipping and movement of the top slab, caused by expansion and contraction and traffic, showing no union whatever between the two unlike materials.

By the vulcanizing process these defects are overcome, and the two slabs of different materials are firmly cemented together.

It is not necessary to have sheet asphalt laid 3 inches thick if asphaltic concrete is heavy enough with a thickness of only 2 inches. Why not lay sheet asphalt, which is denser and harder than asphaltic concrete, 2 inches thick on a concrete base and save the expense of the unnecessary binder and the expense of the extra 1 inch of excavation? The results would be equally permanent and a great saving made. Let us go still further. If the Greco Heater method can vulcanize a sheet asphalt on a smooth concrete surface, why not save more money in

laying new pavements by cutting out the binder and laying 1½-inch sheet asphalt surface or even 1 inch?

In many cities and towns the street railway companies are abandoning their car tracks and transporting passengers by motor busses. This necessitates the removal of the block paving, rails and ties, and the laying of a new pavement in the track space. The cost of doing this is quite heavy and the interruption to traffic long and costly.

A better method at half the cost is to leave the old rails and paving in place to serve as a foundation, and vulcanize a new surface on top.

This vulcanizing process is bound to revolutionize the methods of street construction and give cities and towns clean, noiseless, sanitary, beautiful and permanent pavements at very small cost.

See the boon to mankind, if you can make two blades of grass grow where one formerly grew, or you can resurface two streets at the former cost of one. You also save the investment in the old pavement. No change of grade is necessary for car tracks, man-hole and catch-basin covers or curbs, and there is practically no interruption to traffic.

New pavements can be built, as well as old ones, by the new process at a great saving in cost to the taxpayers.

OF GENERAL INTEREST

WHAT ASPHALT IS

Facts relative to the Characteristics of Asphalt and its Development and Application

*By Charles F. Knowlton **

Asphalt, or asphaltum, is defined as a black or brownish-black non-oxidized bituminous hydrocarbon, semi-fluid to hard in consistency — the heavy residuum from petroleum or occurring naturally. Among its usual properties it is cementitious, impervious to water, resilient, more or less ductile, elastic, to a certain degree fire-resistant, and dustless when employed as paving. Chief among its properties is that decay-resisting quality which makes for long life and endurance. The application of this substance to its many uses is dependent upon its degree of consistency or hardness, and in the manner in which it is affected by temperature changes.

Asphalts derived from petroleum by refining or reduction methods are varied in their physical and chemical characteristics, governed by both the source of the petroleum and the method of preparation. Native or natural asphalts occurring in deposits throughout the world, and of which there are a score or more types, are to a certain extent prepared and marketed, and classified and graded into groups according to their peculiar properties. Some grades are totally unfit for paving purposes, for example, but make excellent records when em-

ployed in the preparation of roofing materials, of insulation for electrical appliances, and of rubber substitutes.

EARLY ASPHALT ROADS

In modern times the earliest record of commercial exploitation of natural asphalt dates in 1802, when the deposits of Seyssel, France, were utilized in the preparation of mastic for bridges, sidewalks and floor surfacings. In 1838 this type of asphalt was introduced into the United States, being employed in the sidewalks of the old Merchants' Exchange Building at Philadelphia.

In 1870 Prof. E. J. Smedt, a Belgian chemist, constructed, in Newark, N. J., what might well be termed the first sheet asphalt plant, and employed rock asphalt for the first time in the United States, in experimental paving work opposite the city hall.

In 1876, rock asphalt from the deposits at Neuchâtel, Switzerland, was used as paving material at Washington, D. C. Later, in 1879, Trinidad asphalt was employed at Washington, and in 1891 some paving was done in the same city with Bermudez asphalt.

The Trinidad asphalt mentioned above was imported from the Trinidad Lake in

* President, Simpson Brothers Corporation, Boston, Mass.

British West Indies possessions. This is one of the most widely known deposits of natural asphalt. This lake is estimated to be from 90 to 114 acres in area, and about 135 feet in depth at its center, where the supply is replenished by a natural flow estimated to amount to about 20,000 tons yearly. The lake is said to contain 6,000,000 tons of asphalt, and shipments from this deposit are reported as being 140,000 tons yearly.

Another lake of importance, which has an area of 1,000 acres, is being exploited in the State of Bermudez, Venezuela, about twenty miles inland from the Gulf of Paria. It is the source of the type of asphalt known and named after the district, — Bermudez.

Following the early successes in paving work at Washington and in Newark, N. J., in the next few years, the asphalt paving industry began to assume greater importance. But it was only after the production of the first commercial asphalt from petroleum — "petroleum asphalt" — that the actual rapid growth of the asphalt paving industry was manifest. In 1910, for example, this new and thriving industry consumed 18,000,000 square yards of asphaltum. Ten years later, in 1920, the utilization of asphalt for paving purposes had mounted to a yearly consumption of 73,000,000 square yards. The next five years saw this figure almost double, when in the year 1925 the industry of road builders applied 138,000,000 square yards of asphalt sheet, asphaltic concrete, and asphalt macadam in road construction. Mounting to 140,000,000 square yards in 1926, this total bids fair to reach the 150,000,000 mark this year.

Pipe Culverts for Highways

*By Dean Peabody, Jr.**

There is an increasing tendency to select all highway materials by test; in

fact, it is obligatory for "Federal aid" roads. The strength of such auxiliary structural features as pipe culverts is checked, also, in this case by compression tests. It is, of course, impossible to duplicate conditions in the ground, but the tests are devised to give comparative indications of the pipe's ability to carry loads when in place.

Culvert pipes may be tested with concentrated load or with sand bearing. Using a "knife edge" concentrated loading, the upper and lower bearings are metal bars, 1 inch wide, bearing on the pipe through a layer of plaster of Paris. "Three-edge bearing" concentrated loads are applied through a single wood block as upper bearing, and two wood strips, 1 inch apart, as lower bearings. When loaded with sand, the pipe is set with a quarter circumference resting in a sand box. A similar frame allows the load to be applied through sand, again bearing over a quarter circumference. Rigging and loading with sand takes much longer than with a concentrated loading test.

Failure first occurs on the inside as a crack running along the upper or lower line of bearing. Somewhat later an outside crack appears in the horizontal diametral plane.

Samples from each shipment can be tested, giving assurance that the product continues uniform in quality and satisfactory for strength. Strength requirements are identical for the two methods of concentrated loading, but are higher for a sand bearing.

Three structural materials are in general use for culvert pipes today, — metal, concrete and vitrified clay.

Metal pipes may be cast iron or sheet metal. The strongest is a lock-joint cast-iron pipe. Spiral corrugated cast-iron pipes are also used. Each spiral pipe screws into an oversize cuff, so that the pipe line consists of alternate pipes and cuffs. Galvanized corrugated sheet

* Assistant Professor of Applied Mechanics, Massachusetts Institute of Technology.

metal pipes are common for light loads, as each unit can be of considerable length.

Concrete pipes may be plain or reinforced. The plain pipe can carry only a comparatively light load. The reinforced pipe is much stronger and does not give a sudden failure. It may be hand made or machine cast. It has been made as large as 6 feet in diameter. Specifications provide for the minimum circular and longitudinal steel.

Vitrified clay pipes are short length, bell and spigot pipes which should be free from blisters and cracks.

The vitrified clay and plain concrete pipes must be used at least 3 feet below the surface, and even then should be a continuous, or closed end, line. An open end line at this depth would take reinforced concrete pipe. The lock-joint pipe can be used as close as 2 feet below the surface.

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS

Designers Section

APRIL 11, 1928. — At 6.15 P.M. the meeting was called to order by the Chairman, William D. Henderson. The minutes of the preceding meeting were read and accepted.

The Chairman then introduced Mr. Ernest B. Bezzozero of the E. & F. King Company, Inc., as the first speaker on the subject of the evening, "Protective Coatings for Metals." Mr. Bezzozero discussed the chemical and physical phenomena of rust, and the action of preservatives. He was followed by Mr. C. E. Dickinson of the Sherwin Williams Company, who described many practical features concerning the uses of paints, varnishes and lacquers.

Both speakers answered questions from the twenty-seven members and guests present.

The meeting adjourned at 7.55 P.M.

NORMAN P. RANDLETT, *Clerk*.

APPLICATIONS FOR MEMBERSHIP

[May 20, 1928]

THE By-Laws provide that the Board of Government shall consider applications

for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of fifteen (15) days from the date given.

For Admission

GERSBACH, ARTHUR F., Mineola, L. I., N. Y. (Age 19, b. Woodhaven, L. I., New York.) Is a junior at Northeastern University. Employed during the summer of 1927 by the city surveyor at Woodhaven, N. Y., as rodman and draftsman; during the fall of 1927 was employed by the town engineer of Stratford, Conn. During co-operative periods in North-

eastern University has been employed by town engineer, Framingham, as draftsman. Refers to *W. J. Alcott, Jr., C. O. Baird, C. S. Ell, J. W. Ingalls.*

MACDONALD, DONALD L., Belmont, Mass. (Age 31, b. Cambridge, Mass.) Student at Tufts College 1916-18; instructor at Tufts Engineering School one year; surveyor, designer and draftsman with French & Hubbard, 1919-20; surveyor, squad chief, expeditor, with C. B. Roberts Engineering Company, 1920-21; instructor in drafting, mechanics and mathematics at Franklin Union, 1921-24; mechanical designer with Stone & Webster, Inc., 1924, and inspector, 1924-28; New England representative, Pittsburgh Testing Laboratory, Boston, to date. Refers to *Robinson Abbott, C. R. Berry, H. P. Burden, D. N. Peaslee, J. F. Wilber.*

MACDONALD, GEORGE ALLO, Taunton, Mass. (Age 19, b. Salem, Mass.) Graduate of Taunton High School and now a sophomore at Northeastern University in civil engineering. In the employ of C. R. Berry, Boston, and the New York, New Haven & Hartford Railroad during co-operative periods. Refers to *H. B. Alvord, C. O. Baird, C. S. Ell, J. W. Ingalls.*

For Transfer from Grade of Junior

RANDLETT, NORMAN PRESCOTT, Boston, Mass. (Age 27, b. Laconia, N. H.) Graduate of Massachusetts Institute of Technology, 1922. Designer and estimator, Berlin Construction Company, Berlin, Conn., October, 1922, to April, 1923; draftsman, Stone & Webster, Inc., April, 1923, to October, same year; structural designer, B. S. Brown, Construction Engineer, October, 1923, to February, 1924; designing draftsman, Blackall, Clapp & Whittemore, February, 1924, to September, same year; designing draftsman, Ritchie, Parsons & Taylor, September, 1924, to September, 1925; structural designer, Monks & Johnson, September, 1925, to October, 1927; structural designer, Dwight P. Robinson Company, Inc., October, 1927, to March, 1928; at present is structural engineer, Coolidge, Shepley, Bulfinch & Abbott. Refers to *Henry Brask, B. S. Brown, J. J. Harty, W. F. Pike, B. A. Rich.*

DEATHS

WILLIAM L. MILLER	April 25, 1928
EDWARD F. MURPHY	April 23, 1928
GEORGE A. SMITH	January 16, 1928

BOSTON SOCIETY OF CIVIL ENGINEERS

FOUNDED 1848

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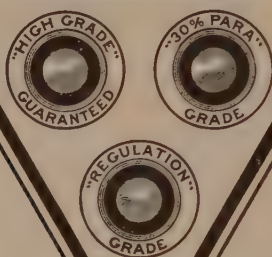
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